Leveraging Mars Aerobraking Experience for the Venus Environment

Tung-Han You
Mark S. Wallace

Jet Propulsion Laboratory
California Institute of Technology

Aerobraking

- The use of atmospheric drag to reduce the period of a spacecraft orbit in a controlled manner in such a way that propellant is saved.
- First used in 1993 by the Magellan spacecraft at Venus as a technology demonstration
- Used operationally at Mars for 20 years:
  - Mars Global Surveyor (MGS): 1997-1999
  - Mars 2001 Odyssey (ODY): 2001-2002
  - Mars Reconnaissance Orbiter (MRO): 2006
  - Mars Atmosphere and Volatile Evolution Mission (MAVEN) “Deep Dips”: 2015 - present
  - Trace Gas Orbiter (TGO): 2017-2018

Key Questions in Aerobraking Trajectory Design

- What drives the timeline?
  - Ascending node of a sun-synchronous final orbit
  - Minimize duration
  - Conjunction
- How deep into the atmosphere can you go?
  - Aerothermal heating
  - Drag torques
  - Mechanical limits
- Operational tempo?
  - Phase duration
  - Team size
- Orbit lifetime requirements?

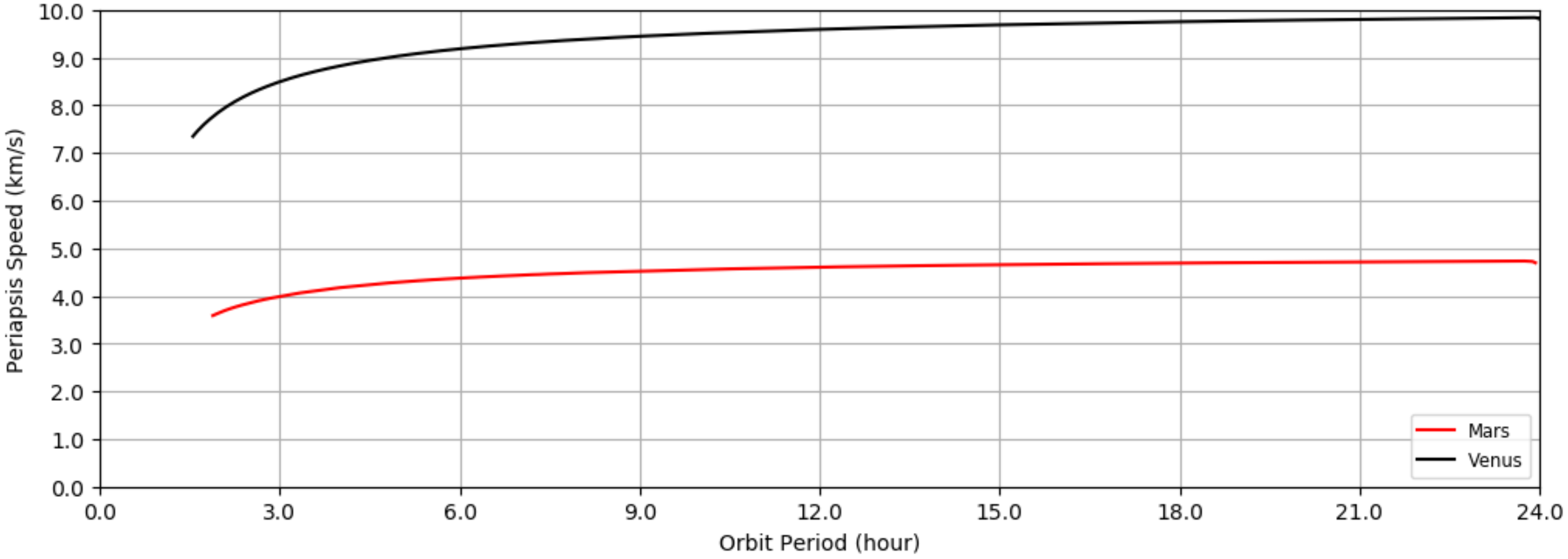
Every mission has different answers to these questions

Aerobraking History

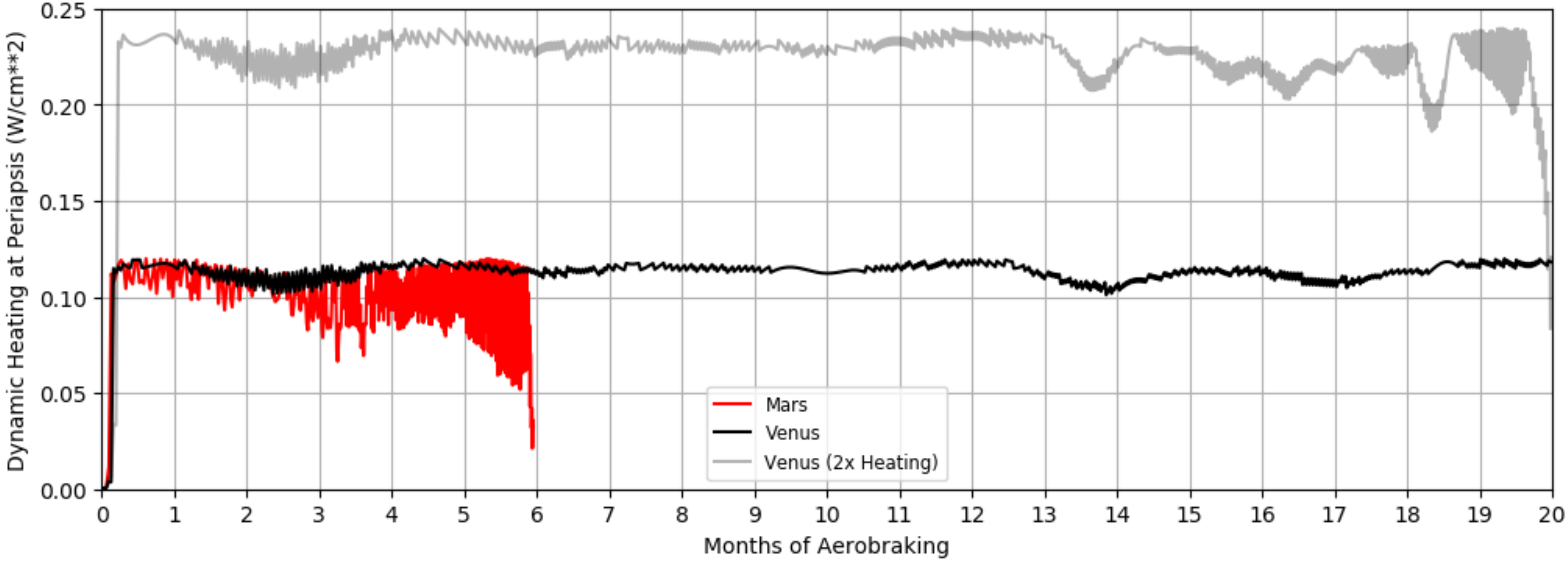
Mission	AB Duration, Month	Period Reduction, Hours	Corridor Control Parameter	Orbit Lifetime, Hours	Key Glideslope Parameters	Onboard Timing Adjust	Pop-up ABM	No. ABM	Remark
MGN (Venus)	**2.4** (1993)	3.2 to 1.5	Dynamic Pressure	N/A	Period	No	0	14	First Planetary Aerobraking
MGS (Mars)	**10.5** (1997-99)	45.0 to 2.0	Dynamic Pressure	48 hours	Period (LMST, Inclination)	No	0	92	Excluded 5.5-month break
ODY (Mars)	**2.7** (2001-02)	18.6 to 2.0	Aerodynamic Heating Rate	24 hours	Period	No	0	33	
MRO (Mars)	**5.0** (2006)	35.0 to 2.0	Aerodynamic Heating Rate	48 hours	Period, (LMST, Inclination)	Yes	0	27	First mission performed PTE in ops
TGO (Mars)	**9.0** (2017-18)	24.0 to 2.0	Aerodynamic Heating Rate	48 hours	Period	Yes	1	67	Excluded 2-month break

Venus vs. Mars

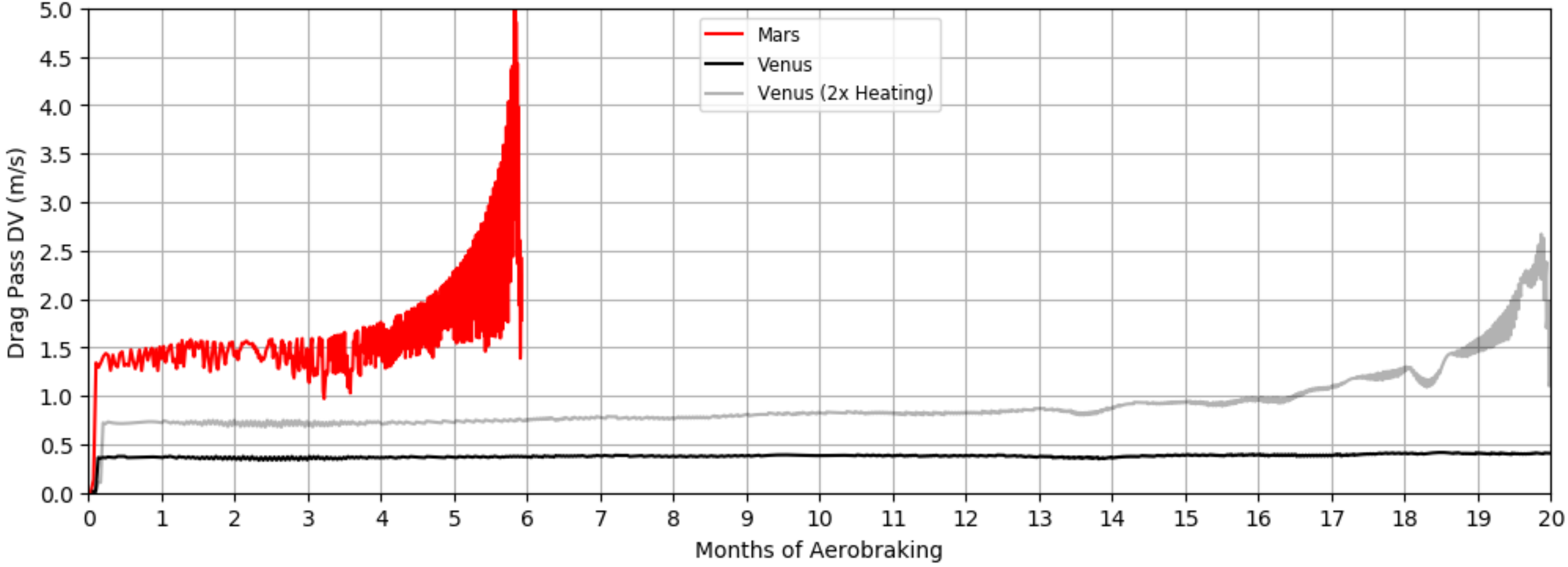
- Venus is half the distance to the Sun
  - Stronger solar tides
  - Increased solar heating
- Venus rotates very slowly
  - Low orbits experience significant eccentricity vector perturbations like lunar orbiters do
- Venus is significantly larger
  - Order of magnitude greater gravitational parameter
  - Periapsis velocity 2.1 times larger
  - Drag goes as square
  - Heating goes as the cube



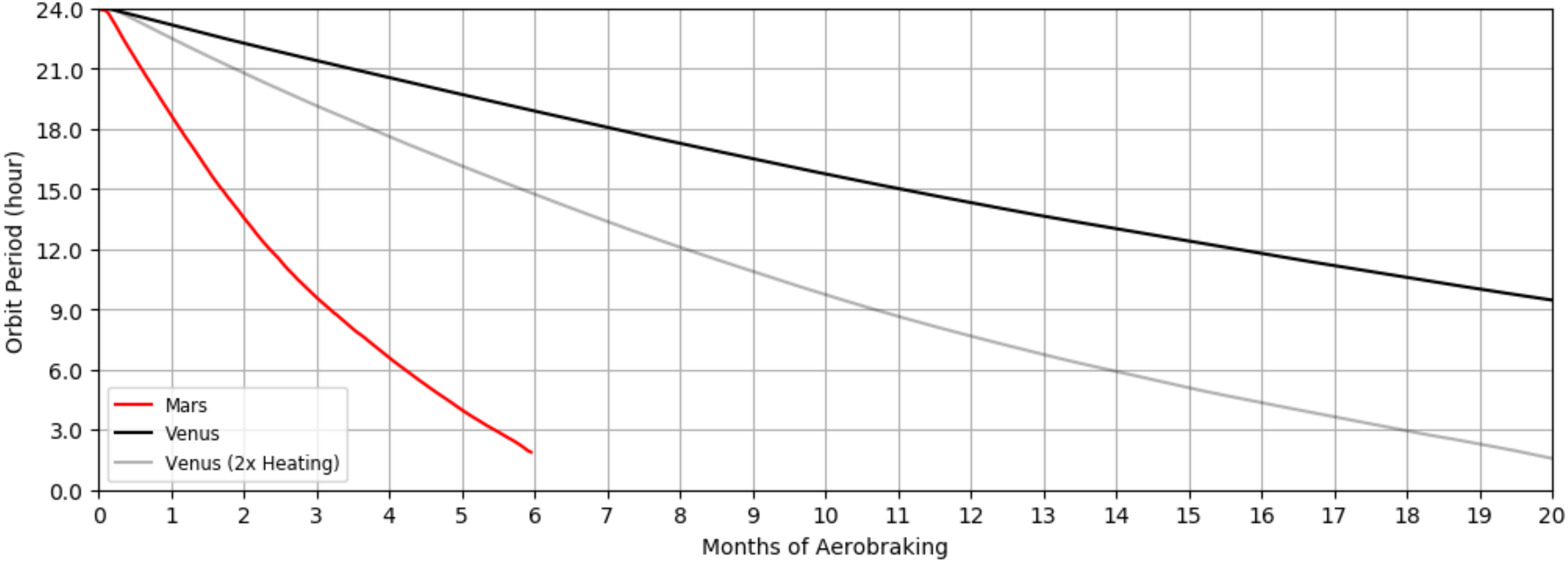
Comparison


Dynamic Heating at Periapsis (W/cm**2)
0.25
0.20
0.15
0.10
0.05
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Months of Aerobraking
Mars
Venus
Venus (2x Heating)

Comparison


Mars
Venus
Venus (2x Heating)
Drag Pass DV (m/s)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Months of Aerobraking

Comparison



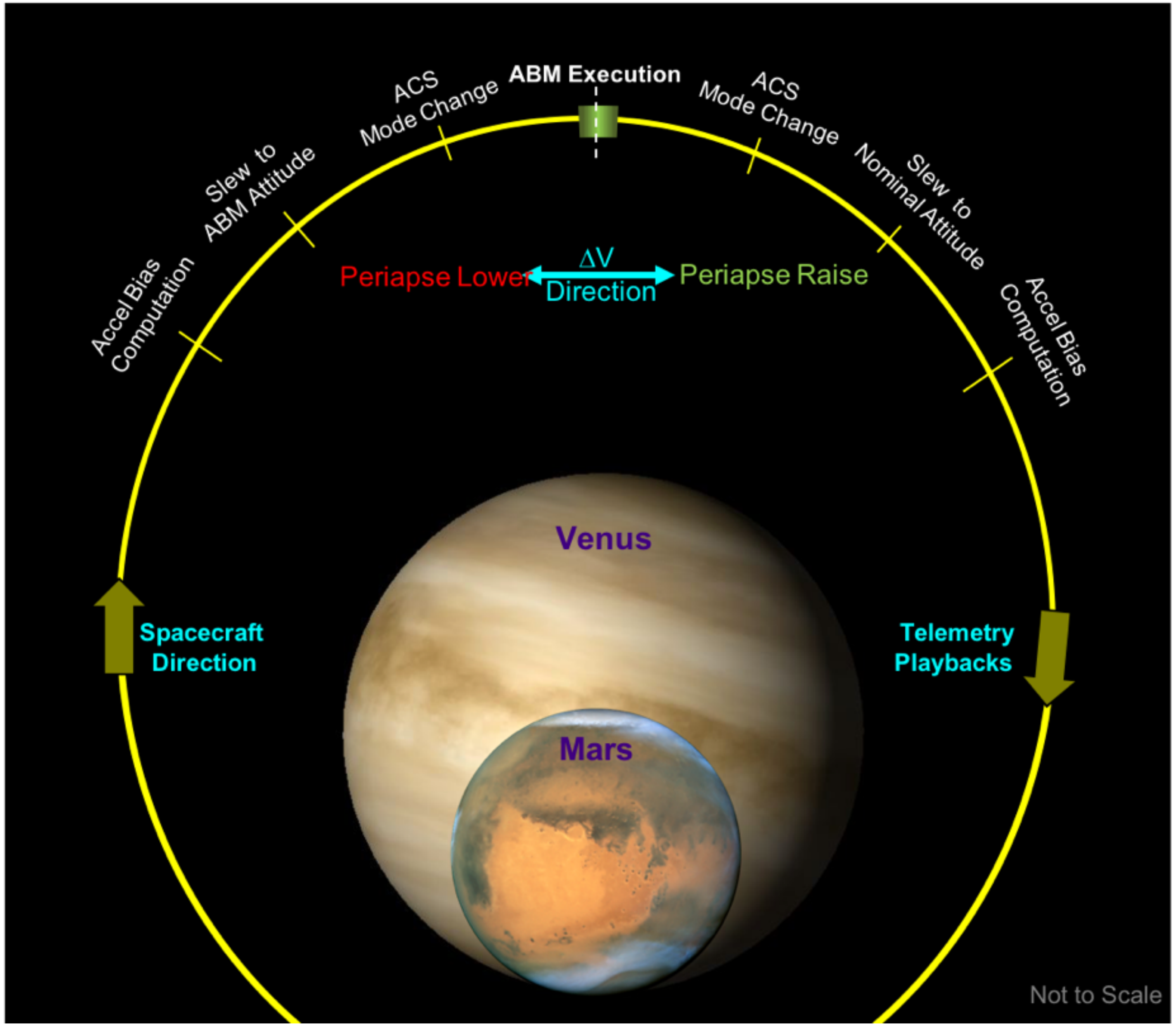
Orbit Period (hour)
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Months of Aerobraking
Mars
Venus
Venus (2x Heating)

Operations

Volatility and uncertainty are the natural a priori of the aerobraking operations. A successful implementation does not rely on how short the aerobraking duration is or the maturity of the atmospheric model. It depends on how well the processes are comprehended and executed with margins.

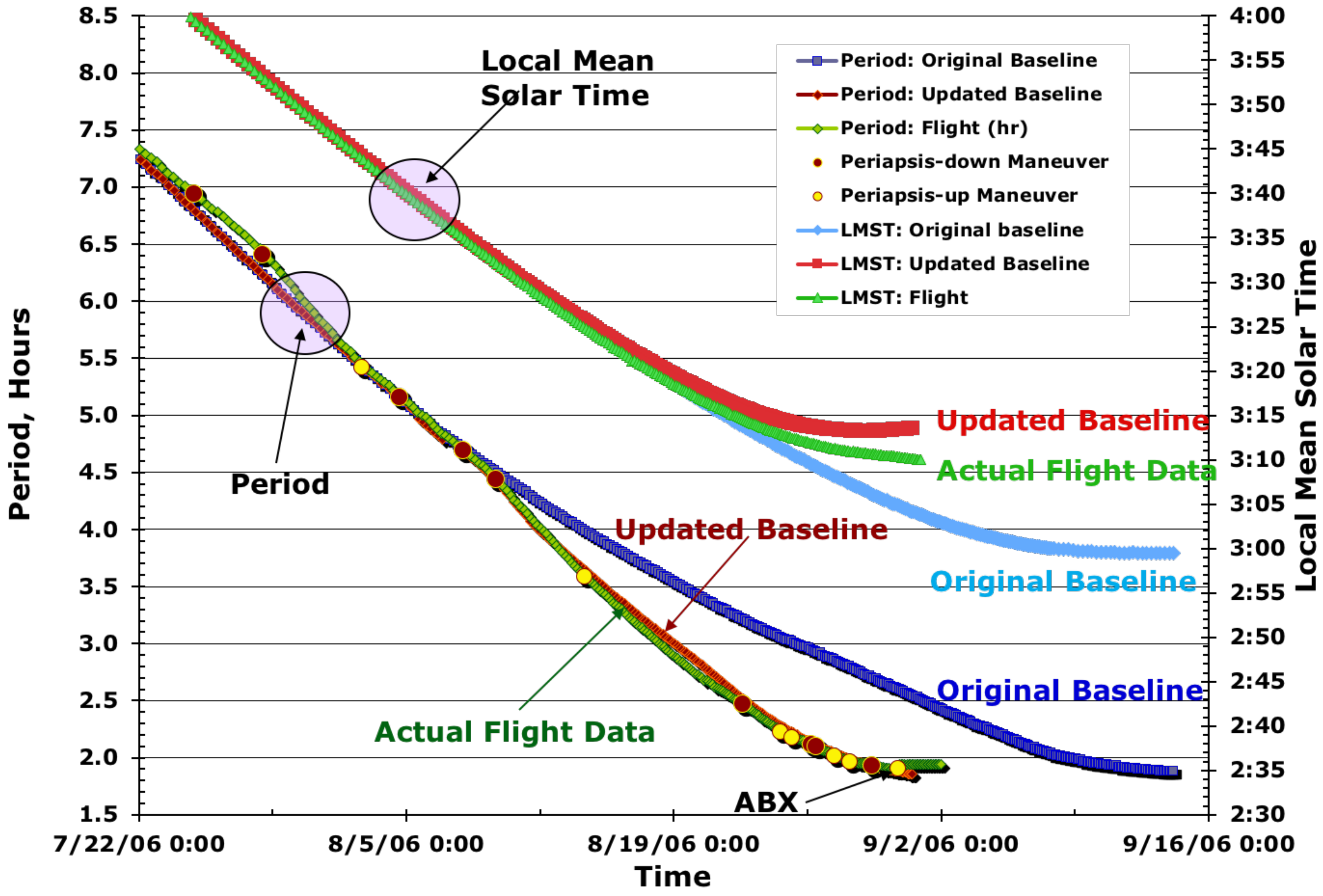
Aerobraking Maneuvers

- Selected from a pre-determined and pre-tested "menu."
  - Typically 10-20 ΔVs, ranging from a few cm/s to several m/s
  - Directions are determined by the on-board ephemeris, either pro- or anti-velocity at apoapsis
  - Using a menu simplifies rapid maneuver sequence development
- Maneuver frequency is typically every other day or less
- Can be automously-driven in the event of a safe mode or unexpected atmospheric behavior



Glideslope

- Design, Trend, and Maintain the "glideslope," or progress toward the designed end state
  - Shown: MRO's ascending node and period
- ABMs are selected based on the glideslope and margins against limits

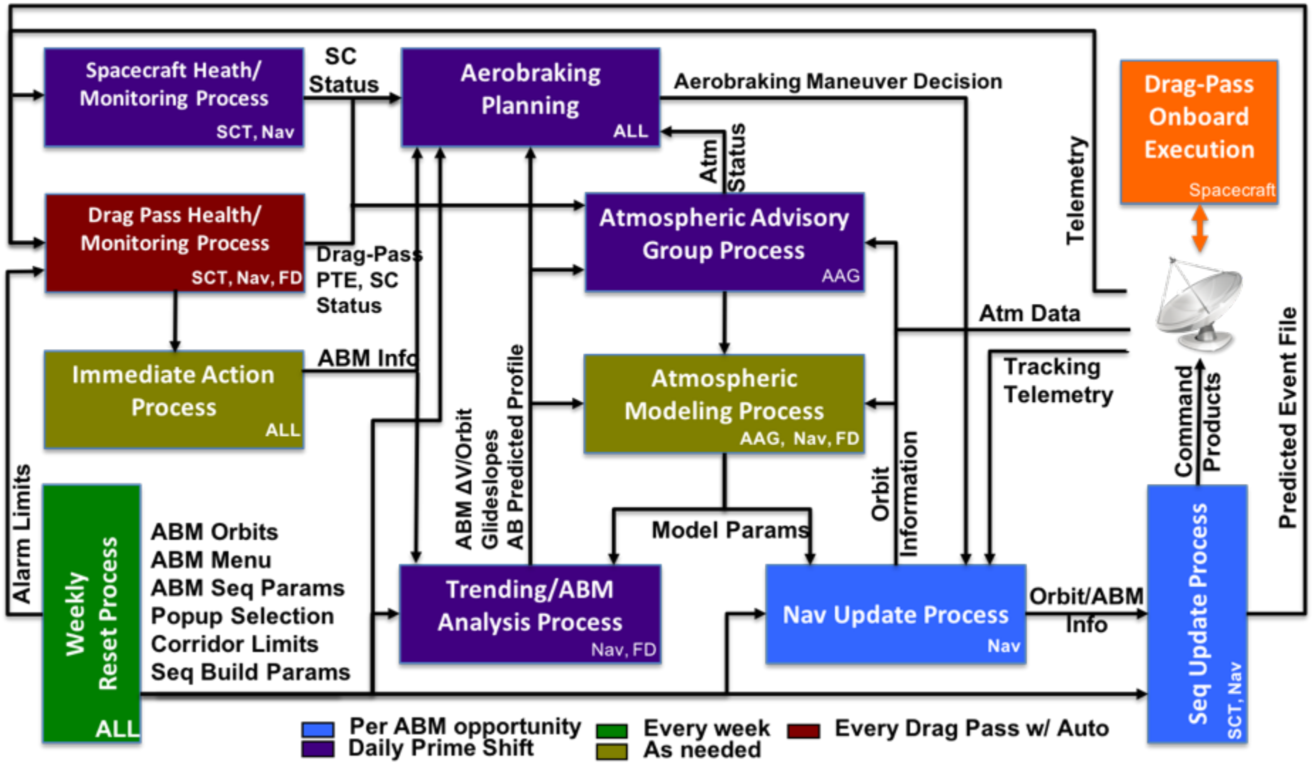


Longer Durations

- Perform science activities and observations during the quiescent period if it is permitted
- Enhance operation processes and procedures
- Improve atmospheric model based on the latest data
- Juvenilize operation teams and train new staff
- Achieve trajectory/orbit phasing strategy to meet trajectory requirements (may save ΔV)
- Rehearse and perform operation readiness tests for the remaining aerobraking
- Adjust design and glide-slope control strategy
- Increase robustness of the aerobraking interfaces and system configurations

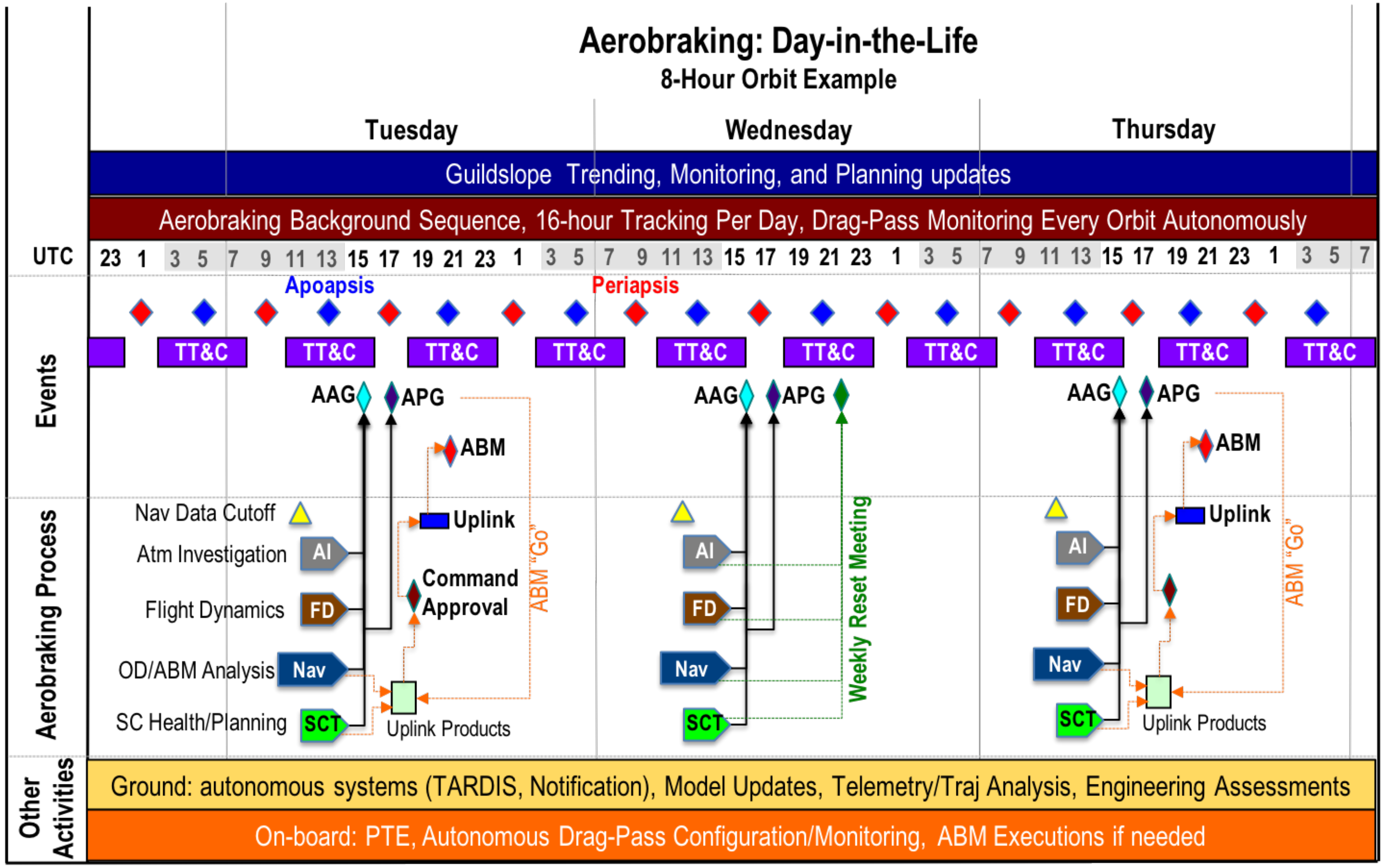
On the Ground

- Teams:
  - Atmospheric Advisory Group (AAG)
  - Navigation Team (NAV)
  - Flight Dynamics Team (FD)
  - Spacecraft Team (SCT)
- Processes:
  - Aerobraking Planning (Tactical)
    - Design to the glideslope
    - ABM Go/No-Go
  - Weekly Reset (Strategic)
    - Re-design the glideslope
    - Update models
  - Immediate Action (Contingency)



Automation

- Periapsis Timing Estimator (PTE)
  - Updates on-board sequences based on accelerometer data and updated orbit period
  - Enables autonomous pop-up maneuvers
  - Prototype flown on ODY
  - First used operationally on MRO
  - Used on MAVEN and TGO
- Traceable Automation with Remote Display and Interruptible Scheduler (TARDIS)
  - Ground-based automation of navigation solutions and trajectory product generation
  - Used for SMAP science operations and TGO aerobraking



Aerobraking Day-in-the-Life with Automation

Prime shift handles maneuvers and weekly resets while Off-Prime shifts are covered by autonomous systems

At Venus

- The long duration of a Venus aerobraking campaign means that the campaign will likely be interrupted by a solar conjunction.
- This pause can permit teams to:
  - Perform science activities and observations during the quiescent period if it is permitted
  - Enhance operation processes and procedures
  - Improve atmospheric model based on the latest data
  - Juvenilize operation teams and train new staff
  - Achieve trajectory/orbit phasing strategy to meet trajectory requirements (may save ΔV)
  - Rehearse and perform operation readiness tests for the remaining aerobraking
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Conclusion

- Venus is not Mars
  - But the differences are well-understood
  - Longer durations have some benefits
- Aerobraking processes are systematized and mature
  - Additions of autonomous capabilities on-board and in the ground systems reduce risk and operational intensity
- Aerobraking was invented at Venus and matured at Mars; a future Venus mission can absolutely benefit